Tensile Stress and Creep in Thermally Grown Oxides

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In-situ Oxidation of Fe-Cr-Al-Y: Composition and Strain Evolution

Motivation

- Understand mechanisms controlling growth of protective oxides.
- Understand relationship between strains and growth processes, factors controlling adhesion

Background

- Structural components operating at high temperatures (e.g., turbine blades) rely on thermally grown oxides (TGO) for corrosion protection.
- For longer lifetime operation and higher operating temperatures, improved oxides are needed.
- Knowledge of strain evolution during growth is needed to understand growth and failure mechanisms.

Compressive Stresses

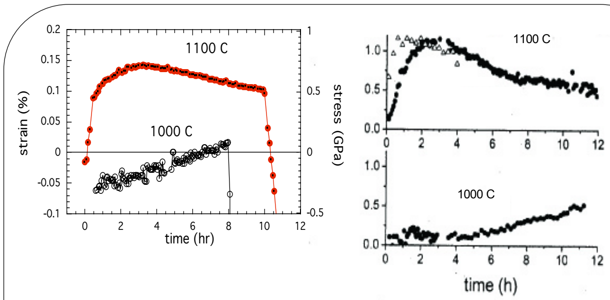
A compressive stress can develop during growth as new oxide forms within existing oxide

Tensile Stresses - Oxidation of FeCrAlY

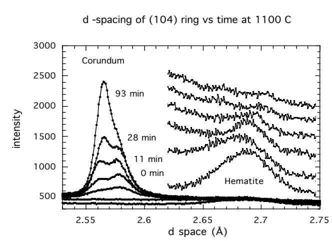
More controversial is the possibility that tensile stresses develop during isothermal growth conditions. In recent XRD studies by E. Specht, et. al (ORNL), it was reported that very large tensile stresses developed during growth at 1100 °C. The mechanism for this surprising result was not identified.

Accomplishment

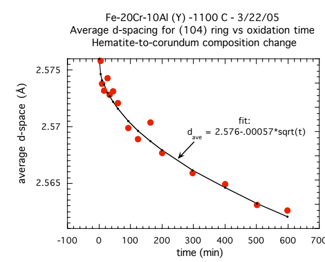
- We confirm the ORNL results and show that a tensile strain develops as the early oxide, a mixed hematite $(Fe,Cr,Al)_2O_3$, converts to corundum, predominately Al_2O_3 during growth. A large reduction in lattice parameter in the constrained oxide leaves the evolving oxide in tension.
- The dominant mechanisms giving rise to the observed strain in the oxide are: the changing composition, generating a tensile stress, competing with creep relaxation which is significant at 1100 °C.
- *In situ* XRD measurements at APS



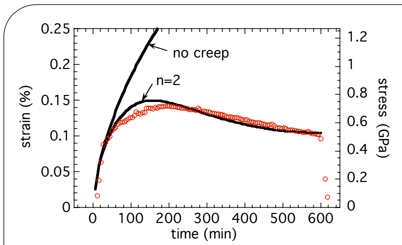
In-plane strain vs time at 1000 and 1100 °C
Left panel: this work
Right panel: Specht, et. Al. (ORNL)



Evolution of $(Fe,Cr,Al)_2O_3$(hematite) to α-Al_2O_3 (corundum)



Change of (104) d-spacing with oxidation time



Open circles: Measured strain.
Upper curve: Strain calculated from d-spacing. No creep is considered.
Lower curve: Creep is included.

At 1100 C, 100 MPa, 0.75 μ grain,
$d\varepsilon/dt = 3.0\times10^{-9}\ sec^{-1}$
$d\varepsilon/dt = 1.3\times10^{-9}\ sec^{-1}$ (Cho, et. al., Lehigh)

Future

- Identify, isolate and quantify the many strain generation mechanisms and relaxation processes in thermally grown oxides.
- This information is essential for understanding and modeling oxide evolution

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